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Potential of distributed photovoltaics in urban Chile

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ABSTRACT

In this article, we present an updated potential of distributed photovoltaics in cities in Chile, which is one of the most promising regions for solar energy utilization because of high insolation, high energy costs and rapid urbanization. The study is based on detailed analysis of the spatio-temporal solar potential including load matching in a southern Chilean city, which is then extrapolated to all cities with more than 15,000 inhabitants. In addition, we estimate the cost-effectiveness of such solar city schemes. Our results show that in the city of Concepción PV could cover up to 90% of the annual electricity demand. On national scale, cities could on average produce 83% of their annual electricity demand, but in the northern part this could exceed even 100%. If scaling the PV yield from distributed PV in cities to whole Chile that would correspond to 22% of country's electricity demand. The cost (LCOE) of PV in cities seems to be cost-effective against grid electricity, i.e. in the Chilean context PV has already reached grid-parity in cities.

1. Introduction

Energy is one of the grand challenges with well-known links to climate change, health, security, nutrition, etc. Fossil fuels still dominate the energy scenery, but their greenhouse gas emissions need to be cut to less than half by the middle of this century as part of the climate change mitigation. This in turn would require a truly global energy revolution shifting to cleaner energy sources such as solar energy. At the same time, the progress of new energy technologies both in terms of their cost reductions and volume growth has been impressive and have turned these alternatives from the margins into a viable future mainstream energy solution. Solar energy as a distributed energy source is also an interesting clean energy option for cities, whose importance will hugely grow as part of the global urbanization trend. Urban and the built environment will definitely play a key role in solving the global energy-climate challenges (United Nations Environment Programme, 2001; Energy Information Administration, 2013; United Nations, 2014). Increasingly these challenges are moving toward developing countries and emerging economies, which often have good solar conditions.

Latin America represents an interesting case for large-scale urban solar energy. By 2050, it is expected that 86% of the population will reside in cities (United Nations, 2014) and both the per capita energy consumption and the total energy consumption are expected to increase throughout the whole region [IEA World Energy Outlook, 2014]. Within the Latin America, Chile possesses good conditions for solar utilization. The price of electricity is high, in cities consumers pay even twice higher price than industrial customers, the solar conditions are very good, even among the best in the world, and the country experiences a severe energy and power problem with social dimensions (Global Energy Network Institute, 2001; Comisión Permanente de Recursos Naturales; IEA-PVPS, 2014). Actually. Chile has become the main market for photovoltaics in Latin America with a total installed PV capacity of 402 MWp in 2014 (Comité Corfo, 2015).

The motivation of this study originates from the evident potential of solar energy for developing economies such as Chile as described above. The main aim in this paper is to assess how much photovoltaics could contribute to the power demand in Chilean cities. The focus is on distributed PV which could be utilized in buildings for on-site electricity production without the necessity to construct new costly energy infrastructure. These kind of large-scale urban PV schemes would be of interest more widely for emerging economies.

Urban solar energy has attracted much interest recently. The theme has been approached e.g. from a policy and economic

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Nomenclature

CIS	Central Interconnected System
EIA	Environmental Impact Assessment
GHG	Greenhouse Gas
IEA	International Energy Agency
ISNG	Interconnected System of Norte Grande
LCOE	Levelized Cost of Electricity
NOCT	Nominal Operating Cell Temperature
N–S	North–South
O&M	Operation and Maintenance
PV	Photovoltaic
PVPS	Photovoltaic Power Systems Programme
VLS	Very Large Scale
WACC	Weighted Average Cost of Capital
β	temperature coefficient
$\tau\alpha$	transmittance–absorptance coefficient
T	temperature (°C)
G	solar radiation (W m^{-2})
V	speed (m s^{-1})
η	efficiency

Subscripts

a	ambient
c	collector
ccp	Concepción
inv	inverter
pp	per person
ref	reference
T	total

impact perspective (Zhanga et al., 2015; Zhao et al., 2015; Yuan et al., 2014) or assessing the solar potential of urban buildings (Li et al., 2015) and even whole cities (Freitas et al., 2015; Gautam et al., 2015; Košir et al., 2014; Redweik et al., 2013). In Chile, most of the studies have focused in assessing the solar availability by large (Molina and Rondanelli, 2012; Escobar et al., 2014) or small settlements (Araya-Muñoz et al., 2014), and the economics of different type of solar power plants (Hanel and Escobar, 2013; Del Sol and Sauma, 2013; Servert et al., 2014). A previous study (Alvarado et al., in press) focuses in the development of a solar map for Concepción, where geo-profiling was used to create a topographical map of all buildings and obstructions, to determine the real solar radiation influx. The data generated in this study, which also includes geo-referenced building classification, serves as basis for this study.

Our approach differs from the previous studies in terms of the spatiotemporal accuracy introduced in the analyses. To accurately assess both the solar resource but also how well it matches the urban power consumption, we analyze the city power consumption and solar access on buildings on a short 1-h time scale over a whole year for each building in a city. We also categorize the power demand profiles by building type which combined with the solar data helps to understand how solar and load matches and in turn to determine a realistic value for the solar potential. We employ the city of Concepción with 300,000 inhabitants as the case for which the detailed analysis is done and then extrapolate the results to whole Chile (cities with more than 15,000 inhabitants) considering population density, urban area, meteorological conditions and differences in average power consumptions. Finally, we also present a short economic analysis for PV in Chile to assess the competitiveness of urban PV against traditional power.

2. Energy situation in Chile

To provide a reference point for the analysis, we shortly describe in the next the energy situation in Chile.

Fossil fuels supply 64% of all electricity in Chile (Generadoras de Chile A.G., 2015). The yearly demand grows on average 5% (Comisión Nacional de Energía, 1998). Due to the geography and topology of the country, two main electric grids have been built. The northern part of Chile is supplied by the Interconnected System of Norte Grande (ISNG), which is dominated by fossil fuels (coal 52%, diesel 28%, and natural gas 19%). ISNG serves 90% of the electricity demand of the important mining and manufacturing industries (Woodhouse and Meisen, 2011). The price of electricity for the ISNG customers is in the range $ 95–117 MW h^{-1}. The central and southern parts of Chile is are mostly supplied by the Central Interconnected System (CIS), whose production portfolio includes both thermal power (55%) and hydropower (41%). CIS delivers 92% of the electricity needed in the households (Instituto Nacional de Estadísticas, 2008), including the city of Concepción where, the electricity price for a typical household is $192 MW h^{-1} (CGE Distribución, 2014).

Due to the high electricity prices for households and high reliance on fossil fuels, the Chilean governments promotes the use of renewable and solar energy, e.g. by green certificates or price regulation. As a consequence, the interest and investments in photovoltaics is rapidly increasing making Chile one of the key new markets for PV in Latin America. Currently, 537 MW$_p$ of PV have been installed and over 1800 MW$_p$ is under construction. Moreover, 56% of the 16,000 MW$_p$ of renewable projects approved by the Environmental Impact Assessment Service are photovoltaics (CIFES, 2015).

3. Methodology

The main focus here is on distributed PV utilization in urban areas. For economics comparison, we also include centralized PV generation, which may find applications in isolated high-radiation desert regions for industrial use. In each case, the PV module performance is assessed using temperature dependent efficiency model (Soto et al., 2005), shown in Eq. (1). The efficiency of the PV system depends on the standard conditions values and the temperature of the cell. A constant efficiency for the inverter was used, of 90%.

$$\eta = \left(\eta_{ref} - \beta_{ref}(T_{ref} - T_c)\right)\eta_{inv} \tag{1}$$

The next step is to calculate the cell temperature. Using the NOCT method and the wind speed dependent heat transfer coefficient (Soto et al., 2005), the cell temperature can be expressed as a function of standard NOCT conditions and environmental conditions, such as solar radiation, wind speed and ambient temperature. Due to the low impact on the result, the transmittance–absorptance ($\tau\alpha$) coefficient is assumed 1. Thus, Eq. (2) is generated to calculate the cell temperature.

$$\frac{T_c - T_a}{T_{NOCT} - T_{a,NOCT}} = \frac{G_T}{G_{NOCT}} \cdot \frac{9.5}{5.7 + 3.8 \cdot v_{wind}} \cdot \left(1 - \frac{\eta}{\tau\alpha}\right) \tag{2}$$